Optik 158 (2018) 1147–1153

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Influence of correlation function on focal switch of a partially coherent beam

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ARTICLE INFO

Article history:
Received 18 December 2017
Accepted 31 December 2017

Keywords:
Focal switch
Correlation function
Partially coherent light

ABSTRACT

It is known that the phenomenon of focal switch depends on the Fresnel number of the lens system, coherence, polarization and amplitude of the incident beam. In this paper, we investigate the influence of the correlation function of a partially coherent beam on focal switch. We study the intensity distribution of an elliptical multi-Gaussian correlated Schell-model (MGCSM) beam focused by a thin lens. It is found that focal switch occurs and we can effectively control focal switch by modulating the structure parameters of the correlation function. Our results provide a novel way for manipulating the focal switch of a partially coherent beam by engineering the structure of the correlation function.

1. Introduction

Focal switch refers to a phenomenon of an increase in the height of the secondary maxima of the axial intensity distribution over that of the original primary one. When it happens, the primary maxima of the axial intensity would experience a sudden transition. It was firstly predicted by Manuel Martínez-Corral et al two decades ago [1]. In 1997, Li studied the properties of a converging spherical wave incident on the Fresnel zone plate and found that focal switch will occur when the Fresnel number of the system decreases to a sufficiently low level [2]. In 2003, Lü and collaborators investigated the propagation of a flattened Gaussian beam through bifocal lenses with and without an aperture respectively [3,4] and found that focal switch will occur through modulating the Fresnel number of the aperture and the Fresnel number of beam. Then the rules of focal switch of coherent beams with different amplitude distributions in mono focal systems were reported [5–13]. In 2005, focal shift and focal switch of a partially coherent light in dual-focus systems were analyzed in [14]. Since then, the influences of the spatial coherence and polarization on focal switch were explored in detail [15–17]. It can be concluded that the occurrence of focal switch is affected by the coherence, polarization, amplitude of a beam and the Fresnel number of the lens system.

The existing investigations on focal switch of partially coherent beams were mainly focused on Gaussian Schell-model (GSM) beam (i.e., conventional partially coherent beam), whose normalized correlation function (i.e., degree of coherence) satisfies Gaussian distribution. Recently, more and more attention is being paid to partially coherent beams with nonconventional correlation functions due to their extraordinary properties and potential applications [18–45]. As a typical example of special correlated partially coherent beam, multi-Gaussian correlated Schell-model (MGCSM) beam whose correlation function is expressed in terms of multi-Gaussian forms was introduced by Sahin and Korotkova, and such beam displays

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https://doi.org/10.1016/j.ijleo.2017.12.208

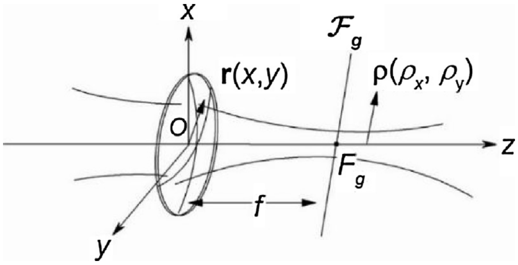

Fig. 1. Geometry of the propagation of an elliptical MGCSM beam through a thin lens. _**g** denotes the geometrical focal plane of the thin lens and the point $\boldsymbol{F_g}$ is the geometrical focus.

circular flat-topped beam profile in the far filed or in the focal plane, which makes MGCSM beam attractive for applications in beam shaping, material thermal processing and optical trapping [34,35]. Rectangular MGCSM beam and elliptical MGCSM beam which produce rectangular and elliptical flat-topped beam profiles in the far field were proposed in [36] and [37], respectively. MGCSM beam carrying a vortex phase was explored in [38]. Generalized MGCSM beam which produces flat-topped or dark hollow beam profile in the far field was proposed in [39]. The propagation properties of a MGCSM beam in turbulent atmosphere have been studied both theoretically and experimentally [40–44], and it was found that a MGCSM beam is affected less by the atmospheric turbulence than a GSM beam, and is expect to be useful in long-distance free-space optical communications. Scattering of a MGCSM beam on a random medium was studied in [45], and optical trapping Rayleigh particles by using focused a MGCSM beam was analyzed in [46]. More recently, Zhang et al. explored the correlation singularities of a MGCSM beam [47]. Focusing properties of a generalized MGCSM beam were investigated and the influence of correlation function on focal shift was discussed in detail [48].

One may ask whether the phenomenon of focal switch is affected or can be controlled by the correlation function of a partially coherent beam. In this paper we will study the intensity properties of an elliptical MGCSM beam focused by a thin lens, and analyze the influence of the structure parameters of the correlation function on focal switch. Some interesting results are found.

2. Analytical expressions for the average intensity of an elliptical MGCSM beam focused by a thin lens

The elliptical MGCSM beam was introduced in [37] as a natural extension of circular MGCSM beam. The normalized correlation function of an elliptical MGCSM beam is expressed as a finite sum of elliptical Gaussian functions, and the elliptical MGCSM beam generates elliptical flat-topped beam profile in the far field or in the focal plane [37]. According to [37], the cross-spectral density of an elliptical MGCSM beam in the source plane is defined as follows

$$\begin{aligned} W(\boldsymbol{\rho_1},\boldsymbol{\rho_2}) = {} & \frac{1}{C_0}\exp(-\frac{\boldsymbol{\rho}_1^2+\boldsymbol{\rho}_2^2}{4\sigma_0^2})\sum_{m=1}^{N}\frac{(-1)^{m-1}}{m}C_N^m \\ & \times\exp\{-\frac{1}{2m}[\frac{(\rho_{x_2}-\rho_{x_1})^2}{\delta_x^2}+\frac{(\rho_{y_2}-\rho_{y_1})^2}{\delta_y^2}]\}, \end{aligned} \tag{1}$$

where$\boldsymbol{\rho_1}$and $\boldsymbol{\rho_2}$ are transverse position vectors in the source plane, C_N^m denotes binomial coefficient with N being the beam index,$C_0 = \sum_{m=1}^{N}(-1)^{m-1}/m$ is a normalization factor, σ_0 is the transverse beam width, δ_x and δ_y denote the transverse coherence lengths along x and y direction respectively. The ratio of the coherence length along y direction to the coherence length along x direction is defined as follows

$$\varepsilon = \frac{\delta_y}{\delta_x}. \tag{2}$$

With the help of the generalized Collins formula [49,50], the average intensity $I(\mathbf{r})$ of a partially coherent beam after propagating through a paraxial ABCD system is given by

$$\begin{aligned} I(\mathbf{r}) = {} & \frac{1}{\lambda^2B^2}\iint W(\boldsymbol{\rho_1},\boldsymbol{\rho_2})\exp\{\frac{-jk}{2}[(\frac{A}{B}\boldsymbol{\rho}_1^2-\frac{A}{B}\boldsymbol{\rho}_2^2) \\ & -2(\frac{1}{B}\boldsymbol{\rho}_1\mathbf{r}-\frac{1}{B}\boldsymbol{\rho}_2\mathbf{r})+(\frac{D}{B}\mathbf{r}^2-\frac{D}{B}\mathbf{r}^2)]\}\boldsymbol{d^2\rho_1 d^2\rho_2}, \end{aligned} \tag{3}$$

where $\mathbf{r}$ is transverse position vector in the output plane, A, B, C and D are the elements of the optical transfer matrix.